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ABSTRACT

Addressing the need for a framework to distinguish the conditions under which different types of educational computing environments are productive, this paper proposes a cognitively based Contextual Analysis Framework consisting of two primary elements: (1) conceptual characteristics of the knowledge domain being learned, including the complexity of the concepts and tasks and the degree of orderly and regular conceptual structure of the knowledge domain; and (2) stage of learning (novice, advanced) of the learner within the knowledge domain. The paper analyzes the characteristics of different types of computer-based learning environments (such as computer-based drill, intelligent tutoring systems, hypertext) in terms of the Contextual Analysis Framework. The paper argues that the failure to consider important contextual elements of learning related to conceptual characteristics of the domain and the stage of the learner could result in otherwise well-designed instructional computing technologies being used in inappropriate learning situations. (Eight footnotes are included; 40 references are attached.) (RS)

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Technical Report No. 527

A FRAMEWORK FOR THE CONTEXTUAL ANALYSIS OF COMPUTER-BASED LEARNING ENVIRONMENTS

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Abstract

The need for a framework to distinguish the conditions under which different types of educational computing environments are productive is addressed, and a cognitively based Contextual Analysis Framework is proposed that consists of two primary elements: (a) *conceptual characteristics* of the knowledge domain being learned, including the *complexity* of the concepts and tasks and the degree of *orderly and regular* conceptual structure of the knowledge domain; and (b) *stage of learning* (novice, advanced) of the learner within the knowledge domain. The characteristics of different types of computer-based learning environments (e.g., computer-based drill, intelligent tutoring systems, hypertext) are analyzed in terms of the Contextual Analysis Framework. It is argued that the failure to consider important contextual elements of learning related to conceptual characteristics of the domain and the stage of the learner could result in otherwise well-designed instructional computing technologies being used in inappropriate learning situations.

A FRAMEWORK FOR THE CONTEXTUAL ANALYSIS OF COMPUTER-BASED LEARNING ENVIRONMENTS

Computing technologies have been applied to instructional situations for nearly 30 years. Despite this fact, the research on the effectiveness of educational computing has been somewhat controversial and has yielded mixed results (Bangert-Drowns, Kulik, & Kulik, 1985; Becker, 1988; Clark, 1985; Kulik, 1981, 1985; Niemiec & Walberg, 1987; Roblyer, Castine, & King, 1988). On the positive side, there have been many findings of small to moderate academic improvement in certain areas and of positive attitudes toward computer-assisted instruction (CAI) in general (Bangert-Drowns et al., 1985; Becker, 1988; Kulik, 1981, 1985; Niemiec & Walberg, 1987; Roblyer et al., 1988). Unfortunately, the quality of some of this research has been criticized, and concerns about methodology have been expressed (Becker, 1988; Clark, 1985; Roblyer et al., 1988). There have also been charges that the educational technology field in general has tended to be atheoretical and neglectful of underlying philosophical issues of central import (Maddux, 1988).

Our primary purpose in this report is to address one fundamental area of theoretical neglect: The need for a framework to distinguish the conditions under which different types of educational computing environments are productive. Just as there are different varieties of educational computing systems that are quite dissimilar from one another, the instructional contexts in which computers are employed can also differ radically. Learning occurs in a highly complex setting, and an understanding of those complexities is necessary if educational computing systems are to be fairly analyzed and appropriately employed. We offer a framework for the analysis of instructional computing systems and of their contexts of use. As will be seen, the proposed framework is grounded in cognitive instructional theory.

We first discuss the components of the Contextual Analysis Framework, then apply the framework to representative types of instructional computing systems, with an analysis of contextual conditions that are likely to promote or hinder the use of each type of system. Finally, we present general considerations concerning the utilization of the framework.

Components of the Contextual Analysis Framework

The Contextual Analysis Framework consists of two primary elements. The first element delineates *conceptual characteristics* of the knowledge domain, and includes the *complexity* of the concepts and tasks and the degree of *orderly and regular structure* in the knowledge domain being learned.[1] The conceptual characteristics element is important in that a learning environment suitable for simple and well-structured content areas may be totally inappropriate for complex and irregularly structured domains (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). The second element consists of the student's *stage of learning* within a knowledge domain and of the associated tasks of learning at different stages (Spiro et al., 1987; Spiro, Coulson, Feltovich, & Anderson, 1988). The analysis of different types of *computer-based learning environments* (e.g., computer-based drill, intelligent tutoring system, hypertext) requires the joint consideration of these two contextual elements; that is, the contextual

[1]We use the term *domain* in a general way to refer to an identifiable conceptual or task unit of human knowledge that can range from quite large (e.g., the entire field of mathematics) to quite small (e.g., single digit multiplication).

elements are *interactive* in their effects.[2] We will briefly introduce these two elements, then discuss the research on learning failures related to them.

Conceptual Characteristics of Knowledge Domains

Well- versus ill-structured knowledge: Degree of orderliness and regularity. The *structure* of the information, tasks, and knowledge domains with which computer-based learning environments must be capable of functioning varies enormously. There have been many recent discussions concerning the distinction between well- and ill-structured concepts and problems in the cognitive science literature (Spiro et al., 1987; Spiro et al., 1988; Elio & Anderson, 1984; Homa, 1984; Simon, 1973; Voss, 1987; Voss, Greene, Post, & Penner, 1983). *Well-structured* content areas (e.g., arithmetic, Newtonian physics) possess a regularity in structure that typically allows for the identification of general rules or principles, hierarchical conceptual relationships, and the use of prototypical exemplars that will closely match a high percentage of real-case situations (Spiro et al., 1987). In contrast, ill-structured domains (e.g., literary interpretation, history, biomedicine) are knowledge areas where many concepts are relevant in a typical knowledge application case and where the patterns of use for each concept and concept combination varies widely across different case situations. While knowledge areas may therefore be differentiated along a continuum of well- and ill-structuredness, we will see that there are qualitatively different instructional implications depending on whether learning situations fall closer to one pole or the other. It is also important to note that well-structured knowledge must often be *applied* in ill-structured (real-world) situations. For example, well-structured basic science components from engineering disciplines must be applied in real-world case situations that are frequently highly ill-structured. Thus, the prevalence of ill-structuredness should not be underestimated.

Domain and task complexity. There is another important aspect associated with the conceptual characteristics of a knowledge area: *domain complexity*. More complex concepts may have to be understood with reference to several other concepts and they may have many constituent subconcepts. Similarly, common tasks that must be performed in a domain may involve few or many steps, branching contingencies, ambiguities, and so on. These and the various other dimensions of complexity are different concerns than those of domain well-structuredness, which has more to do with orderliness and regularity in the application of concepts and operations across cases within a domain.

Domain complexity is correlated with the degree of well- or ill-structuredness in a knowledge area, with simple tasks or concepts tending to be well-structured while more complex concepts or domains are often ill-structured. The association of domain complexity and structuredness is, however, far from perfect. While there are few, if any, areas that are both simple and ill-structured, there are many domains that may be characterized as being primarily complex but well-structured in nature (e.g., advanced mathematics, physics, physiology). For example, the generalization and rigorous definition of mathematical principles and rules, the strong delineations of task hierarchies in the application of mathematical concepts, and the ability of prototypes to apply to all case examples of the same type are hallmarks of the domain of mathematics. Yet despite its extensive orderliness and regularity (i.e., well-structuredness), mathematical concepts and tasks are often quite complex. It is also interesting to note that an area that is largely well-structured at elementary through intermediate-advanced levels frequently assumes characteristics of ill-structuredness at the "cutting edge" of the field. This is seen, for example,

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[2]There are, of course, other contextual elements that influence the learning environments in which instructional computing systems must be used, such as *individual learner characteristics* and *social and cultural conditions*, that will not be addressed in this report. While these are important factors, we view the present articulation of the framework as a significant first step toward a more suitably elaborate theoretical view of the complexity of this field.

in the current research interest in "chaos theory" in such fields as mathematics, the natural sciences (see Gleick, 1987, for a nontechnical account), and even the social sciences (Cziko, 1989).

Stages of Learning: Introductory and Advanced Knowledge Acquisition

While much recent cognitive literature has described novice/expert differences (Chi, Glaser, & Farr, 1988; Glaser, 1984; Vosniadou & Brewer, 1987), the lengthy intermediate stage of learning between the beginner and the expert has received much less study. It has been recently proposed that a stage of *advanced knowledge acquisition* or *advanced learning* occurs after the introductory stage of learning in a subject area and before domain expertise is achieved after extensive study and experience (Spiro et al., 1988). While introductory learning goals typically stress surface familiarity with key concepts that are assessed in terms of recognition and recall tasks, the goals of advanced knowledge acquisition change so that the learner must acquire a richer and deeper understanding of the content material. The advanced learner must be able to intelligently reason with and to *apply* flexibly acquired knowledge in a wide range of situations that may differ substantially from the conditions of initial learning (i.e., knowledge transfer).

Complexity, Ill-Structuredness, and Failure in Advanced Knowledge Acquisition: The Importance of Context-Based Adjustment of Learning and Instructional Strategies

The importance of matching learning and instruction to contextual factors such as those just discussed can be illustrated by an examination of recent research that has revealed patterns of extensive deficiency in the learning outcomes of students at the stage of advanced knowledge acquisition, particularly in complex and ill-structured content areas (Feltovich, Spiro, & Coulson, 1989; Spiro, Feltovich, Coulson, & Anderson, 1989; Spiro et al., 1987; Spiro et al., 1988).[3] The failures of advanced learning that have been identified are attributable to several converging tendencies on the part of students, teachers, textbook writers, test constructors, and so on. In general, the common denominator across the failures is a strong bias toward *oversimplification*. Among the variety of oversimplifications that have been observed to cause learning failure at advanced stages are: *compartmentalization* (i.e., slighting the interrelationships among knowledge components and topics); employment of a *single basis for knowledge representation* (e.g., a single analogy, prototype example, organizational scheme, or line of argument); emphasis upon the *intact retrieval from memory* of previously learned knowledge (i.e., rigidly using packets of knowledge in the same way that they were initially learned and stored in memory); and *overreliance on abstractions* divorced from their contexts of application. In fact, instructional approaches employing simplifying strategies such as these are often the most successful ones for *introducing* a student to a new subject area. Unfortunately, what helps early in learning often hurts later on (a phenomenon that has gone unnoticed because of the previous dearth of studies of the intermediate stage of learning between novicehood and expertise) (Feltovich et al., 1989; Spiro et al., 1988; Spiro et al., 1989).

Advanced knowledge acquisition in complex and ill-structured domains requires instructional approaches that are often *antithetical* to those used in introductory learning and that are most appropriate for simpler domains (Spiro et al., 1988), such as: *webs of interrelated knowledge* instead of independent knowledge compartments; *multiple knowledge representations* (e.g., multiple analogies, precedent cases, organizational schemes, lines of argument); *assembly* of relevant knowledge from different conceptual and case sources to adaptively fit the needs of new situations; and *concepts tied to practice* (i.e., conceptual knowledge situated in contexts similar to those required in the application of the knowledge). Such instructional features function as *antidotes* to the oversimplifying tendencies identified earlier and

[3]Of course, as learners reach more advanced levels of attainment in any domain, the importance of dealing with the more ill-structured, irregular aspects of knowledge grows.

are vital in cultivating the *flexible cognitive representations* that are characteristic of expertise and that will facilitate the ability of the learner to apply existing knowledge to new situations.

It is important to emphasize that when the concepts and phenomena of a domain are simple and orderly, the ideal of simplicity in instruction is appropriate. However, when a domain is complex and ill-structured, and when the goals of learning require that difficult aspects be mastered, then transporting the methods that work in simple and regular conceptual contexts may have severe deleterious effects (Feltovich et al., 1989; Spiro et al., 1988; Spiro et al., 1989).

In summary, the example of failure in advanced knowledge acquisition illustrates a crucial point: *Totally different approaches to learning, instruction, and mental representation are required in well- versus ill-structured domains, for simple versus complex concepts, and for the goals of introductory versus advanced learning.* The very same approaches that typically result in successful learning in well-structured domains, for simple concepts, and for introductory learners, have been found to be unsuccessful in ill-structured domains and may actually *impede* the acquisition of complex concepts at advanced stages of learning in a domain (Feltovich et al., 1989; Spiro et al., 1989). Furthermore, the approaches that appear to be better suited to contexts of irregularity, complexity, and advanced learning are very often the *opposite* of those that most efficiently produce success in regular, simple, and introductory contexts. Thus, these two contextual factors--conceptual characteristics of the knowledge domain (conceptual structuredness and complexity) and stage of learning--must be taken into consideration in the evaluation of any approach to learning and instruction, including those that involve computers.

Application of the Contextual Analysis Framework to Computer-Based Learning Environments

The central assertion of the Contextual Analysis Framework may be simply summarized: *depending on where a teaching situation falls within the contextual space of domain conceptual characteristics and stage of learning, qualitatively different forms of instruction must be prescribed.* Some of the implications of this perspective for the analysis and use of computer-based learning environments are our concern in this section of the report. After briefly considering the major types of computer-based learning environments commonly employed, we will illustrate the application of the Contextual Analysis Framework through a detailed examination of two contrasting instructional computing systems. We will conclude this section with a consideration of more global applications of the framework.

Types of Computer-Based Learning Environments

We use the phrase *computer-based learning environments* (CBLEs) to refer to both earlier educational computing approaches (e.g., computer-assisted instruction and the use of computer tools such as word processing) and more recent instructional systems (e.g., intelligent tutoring systems [ITS], microworlds, hypertext, and empowering environments). The earlier literature on instructional computing typically describes three main ways that computers may be employed: (a) a mechanism to deliver instruction (e.g., computer-assisted instruction [CAI] approaches such as tutorials, computer-based drills, and simulations); (b) a tool that students may use to accomplish a variety of tasks (e.g., word processing, spreadsheets, data bases); and (c) a device that may be programmed by students to accomplish new computer-based tasks or for general problem-solving experience (Bork, 1985; Dennis & Kansky, 1984; Taylor, 1980). Most of the research on the effectiveness of computers in education has focused on these types of CBLEs (Bangert-Drowns et al., 1985; Becker, 1988; Clark, 1985; Kulik, 1981, 1985; Niemiec & Walberg, 1987; Roblyer et al., 1988).

Other recent approaches to using computers in instruction have attempted to utilize research into cognitive processes to more closely simulate the teaching of a human tutor by a computer system or to establish computer-based learning systems that provide some type of cognitive support for the learner

(Brown, 1985; Collins & Brown, 1988, Dede, 1987, 1988; Sleeman & Brown, 1982; Wenger, 1987). Intelligent tutoring systems (ITS), for example, attempt to "understand" the content and the student's progress, thus facilitating the individualization of instruction (Dede, 1987, 1988). Other contemporary CBLEs, for example, hypertext (Dede, 1987; Conklin, 1987; Jonassen, 1986), microworlds (Dede, 1987, 1988; Papert, 1980), and empowering environments (Brown, 1985; Collins & Brown, 1988; Dede, 1987, 1988), are designed to function in partnership with the student or teacher. The latter CBLEs attempt to provide a synergistic combination of the cognitive strengths of humans for processing rich, interconnected knowledge and the computer's large short-term and long-term memory capabilities and strength in the rapid execution of complex algorithms and symbol manipulation (Dede, 1988).

Applying the Analytical Framework: A Detailed Analysis of Two Representative Computer-Based Learning Environments

The Contextual Analysis Framework we are proposing suggests that different types of CBLEs are better suited to different learning contexts. The framework guides the selection of an appropriate CBLE to promote learning in the target instructional situation as a function of the conceptual characteristics of the knowledge area (domain structuredness and complexity) and the student's stage of learning. For example, because of distinctive cognitive design characteristics, certain types of CBLEs are regarded as being most applicable to simple and well-structured content areas or to introductory learning situations (e.g., CAI tutorials appropriate for simple and well-structured domains, but not for complex and ill-structured knowledge), while other systems are analyzed as having their major applicability at the advanced stage of learning and in domains with higher levels of complexity and conceptual ill-structuredness (e.g., instructional hypertext systems). To demonstrate the application of the Contextual Analysis Framework, we will first provide a detailed examination of two contrasting educational computing approaches: a computer-based drill and a hypertext learning environment.

Computer-based drill systems. There are several factors that may be considered when analyzing the contextual elements associated with a hypothetical computer-based drill program. Let us take, as an example, a typical use of a computer-based drill that involves a student learning the multiplication table. First, a learner of this type of information is usually in the middle elementary grades and is thus at an *introductory stage of learning* with respect to mathematical knowledge. Student learning of the multiplication table is typically assessed in terms of tasks that require the accurate retrieval from memory of the previously learned knowledge (e.g., "7 x 8 = 56"), a practice that is consistent with introductory stage learning goals discussed earlier. Notice that the universe of all possible mathematical knowledge relevant to multiplication has been greatly *simplified*, with more advanced mathematical concepts such as set theory or the algebraic formulation of multiplication not being explicitly included in the instructional activities commonly associated with merely memorizing the multiplication table. Here we are concerned only with the latter task.

Second, the *conceptual characteristics* of the basic multiplication table are orderly and relatively simple. The well-structured nature of this domain is reflected in the existence of orderly and consistent patterns (e.g., 2 x 1, 2 x 2, 2 x 3), and there is a high degree of conceptual regularity in that the same principles apply to all pertinent examples (e.g., learning an instructional example of "2 times 3 apples equals 6 apples" easily transfers to a new situation requiring the determination of "2 times 3 elephants"). The conceptual complexity of this domain is reasonably simple (compared, for example, to quadratic equations), consisting of such elementary arithmetic concepts as basic attributes of numbers, simple arithmetic symbols (e.g., digits, "x", "="), and so on.

From the perspective of the Contextual Analysis Framework, there are several common design characteristics of computer-based drill programs that seem appropriate for learning the "multiplication table domain." Computer-based drill systems tend to present the instructional material in a simple manner that is suitable for this type of content and stage of learning. For example, a *single knowledge*

representation (a stimulus such as "What is 7 x 8?" is employed to elicit a specific response: "56"). The multiplication knowledge is drilled in a manner *abstracted from application settings*, which shields the learner from having the additional cognitive demands associated with a complex problem solving situation with potentially distracting information unrelated to the task of multiplying numbers. In terms of promoting the goals of introductory stage learning, computer-based drill designs help facilitate the *memorization* of the material by providing concentrated practice with immediate feedback to the learner in terms of the correctness of the response, and more sophisticated designs may monitor the patterns of the correct and incorrect responses to provide the learner with more practice on difficult items.[4]

Given this analysis based on the Contextual Analysis Framework (and with the caveat that we do not recommend computer-based drill programs as the sole instructional methodology for teaching the multiplication table domain), we suggest that computer-based drill programs have several features (e.g., simplified representation of multiplication knowledge, feedback on single correct answers, emphasis on factual recall) that are appropriate for promoting introductory stage learning in a simple and well-structured knowledge domain of this type.

Instructional hypertext and hypermedia systems. In this section we consider the contextual elements associated with advanced learning in a complex and ill-structured domain: interpretive comprehension of the classic literary film *Citizen Kane*. While the elements of the Contextual Analysis Framework associated with this cinematic/literary domain differ sharply from those of the multiplication table domain described in the computer-based drill example, we will show that there is an apt fit between these contextual features and the characteristics associated with hypertext learning environments. The CBLE we will discuss is a hypertext system (Spiro & Jehng, 1990) derived from a cognitive theory of learning for transfer in complex and ill-structured domains (Spiro et al., 1987; Spiro et al., 1988).

First, with respect to *stage of learning*, the intended use of the hypertext system is for *advanced learners*: college students (or select high school students) who have acquired a general awareness of the film during a period of introductory learning (typically including one or two complete viewings of the film), and who are now expected to demonstrate learning that goes beyond reproductive memory for superficial information about the film. They are expected to evince more sophisticated understandings of the complex structure of the film and to be able to independently address relevant new questions for which they have not received direct instruction (i.e., transfer of learning is expected).

Second, with respect to the *conceptual characteristics* of *Citizen Kane*, it is clear that the film is quite complex and ill-structured. This is reflected in the numerous aspects of the film discussed in the critical literature (e.g., plot, characterization, cinematic techniques). Many aspects of complexity and conceptual irregularity are revealed in considerations of a central component of the film: Kane's behavior, motivations, problems, and so on.[5] Different experts have proposed a number of themes as providing a complete description of Kane's behavior, such as: "Hollow Man" (the soullessness of Kane), "Wealth Corrupts," and "Outsized Ambition." While these themes do partially overlap, each theme makes a novel contribution toward understanding the Kane character that is not found in the other themes--there is no single "main theme" that is best for capturing the nature of Kane and accounting for his behavior. At different points in the film different themes are relatively ascendant--all themes do not equally apply to all scenes in the movie (e.g., certain themes may be strongly relevant to some scenes but not to

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[4]No claim is made that sterile memorization of multiplication tables is the best first step toward preparing learners to apply multiplication facts to real problems. In fact, our earlier argument suggests just the opposite: The early simplification may impede the learner in building toward more complex understandings. However, if all you want to do is memorize the multiplication tables, computer-based drill systems are appropriate.

[5]This type of analysis could be profitably extended to include additional aspects of the film.

others). Not only are multiple themes necessary for understanding Kane across the film as a whole, but any single point in the film is likely to require analysis in terms of interactive combinations of more than one theme. Furthermore, each theme is not used in exactly the same way at every point in the film where it is relevant. Rather, the different uses (instantiations) of each theme are related to each other only by a rough family resemblance (instead of by a set of defining features).

We have presented just a few illustrations of the features of complexity and ill-structuredness that are confronted in trying to achieve an advanced understanding of the Kane character. However, it should be clear even from this brief presentation that the structural characteristics of this knowledge domain (e.g., the large number of pertinent conceptual structures and the fact that they interact in combination with each other) make the attainment of the goals of advanced stage learning quite difficult compared to simpler and more orderly domains. Nonlinear and multidimensional hypertext systems are especially well matched to the instructional context of advanced mastery of complex and ill-structured material. We will next highlight an approach to structuring a hypertext learning environment that has been specially designed to address these features of complexity (including many not mentioned here) that present such great trouble for advanced learners (Spiro et al., 1988).

A prototype instructional hypertext system has been developed to provide advanced stage learning of the aspects of this film associated with the Kane character (Spiro & Jehng, 1990). While only a portion of the movie has been analyzed and incorporated into this instructional hypertext program to date (25 scenes lasting a total of about 30 minutes from side two of the *Citizen Kane* videodisc [Welles & Stein, 1984]), this material constitutes a rich instructional knowledge base the learner may study. Some of the complex conceptual structure of the movie is represented by the inclusion of 10 major themes found in the critical literature on the film, each of which could be argued to be the most important one for understanding the Kane character.[6] The 25 scenes selected for instruction are treated as self-contained "minicases," each of which is analyzed from the perspectives of a subset of the 10 major themes relevant to that scene, as they interact in any combination. Minicase-specific thematic commentaries relate the more general and abstract nature of each theme to the particular scene being viewed. Not only can the film be viewed with each of the scenes being shown and studied in detail in a sequential manner, but the film may also be *re-edited* by the program to allow the learner to select a particular theme (or combination of themes) of interest and to view only those scenes in which the selected theme (or themes) applies. For example, suppose a learner is interested in the relationship of the "Hollow Man" and the "Power Corrupts" themes. The program would allow the hypertext link structure to be arranged so that the learner would view only those minicase scenes that contain both of these themes (and to read the associated thematic commentaries tailoring the themes to the particular scenes). When scenes are viewed out of their original sequence, stage-setting background information can be requested. There are also program options for learners to create their own structural schemes in addition to using the preprogrammed options.[7]

Even with this cursory description of the *Kane* hypertext, it is possible to illustrate several features that make it an appropriate computer learning environment for its instructional context (i.e., advanced stage

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[6]Note that while the exact number of themes employed is not critical, it is important that several themes be employed and that these themes have a fairly wide coverage in the domain. In an ill-structured domain, nearly all themes have some degree of "correctness" (but only to a limited extent) and the irregularity of the conceptual structure is best revealed by multiple perspectives (such as the multiple themes and scene units/minicases employed in this program [Spiro & Jehng, 1990]).

[7]The hypertext under discussion is just one of several hypertext prototypes developed by Spiro and his colleagues. Each of the systems is generated from the same rich core set of principles. The interested reader will find more extended explications of the approach in Spiro et al. (1988) and Spiro and Jehng (1990).

learning goals for a complex and ill-structured knowledge domain). For example, the complexity of the film cannot be understood from any single perspective, which would have to be inadequate because of the film's ill-structured nature. The hypertext program allows the learner to view the film from *multiple thematic perspectives*, each of wide application. This also facilitates transfer by increasing coverage within the domain: If knowledge has to be used in many ways, as it will in an ill-structured domain (by definition), it should be learned and mentally represented in many ways.

Where there is a problem in ill-structured domains because generic or abstracted concepts miss too many specifics of particular applications of a concept, the case-centered approach of this program provides *situated conceptual knowledge* in the context of scenes from the film. For example, the conceptual thematic information (presented in the auxiliary commentaries) is "tailored" to its context of application (helping to prepare the learner similarly to adapt abstract conceptual information to concrete cases). The learner develops an understanding of the abstract themes that is situated in the actual context of application of this knowledge (e.g., the actual scenes from the film itself), thus avoiding the tendency toward simplification that may result from abstracting the knowledge away from the situations and conditions of use (as would tend to occur if the learner were to read the abstract thematic descriptions without being able to view appropriate segments of the film itself).

The program's theme search feature addresses a related problem of irregular domain structure, *conceptual variability of application*. The theme search feature allows the learner to see a series of scenes from the film each of which is an illustration of the given theme. In an ill-structured domain the same nominal concept takes different forms on different occasions; by enabling the learner to see a chronologically nonadjacent series of these varying uses of the same concept sequentially, attention is drawn to the nature of the variability in that conceptual theme's usage. Again, if knowledge has to be used in many ways, as it will in an ill-structured domain, it should be learned in many ways.

Furthermore, learning difficulties are caused by the fact that different *combinations of conceptual structures* tend to be relevant at any one time, and the meaning of each concept is affected by the others with which it co-occurs. This aspect of complexity is addressed by allowing the learner to explore (with more or less explicit guidance) any possible combination of the concepts: A configuration of concepts is requested and scenes from the film that exemplify that combination are shown in sequence.

In this manner, *interconnected webs* of knowledge are built that are far more accurate representations of the complexity of the domain than compartmentalized understanding would be. Relatedly, the problem of transfer is compounded by the fact that in ill-structured domains such as this one, new uses of knowledge require *assemblies* of conceptual knowledge that can take many forms and can not be anticipated in advance. Cross-references to other parts of the knowledge space that are encountered when interacting with the program establish routes of interconnection for future knowledge assembly while at the same time implicitly modeling the interconnected nature of the knowledge and thus the assembly process itself.

Thus it can be seen that the features of this hypertext learning environment are quite tailored, on many different dimensions, to the needs of advanced stage acquisition of complex and ill-structured knowledge. In a variety of ways, the complexity of the domain is "covered" and learners are prepared to use their acquired knowledge in an adaptively flexible manner. Again, there are many other features of this approach to structuring an instructional hypertext that illustrate its fit as a CBLE for a complex and ill-structured educational context that are consistent with our proposed Contextual Analysis Framework (see Spiro & Jehng, 1990 for a more complete discussion).

Inappropriate uses of computer-based drill and instructional hypertext approaches. In the previous two sections, we have stressed the *fit* between two specific types of CBLE and critical components of their respective contexts of use, in terms of the Contextual Analysis Framework. We will now consider

the consequences when the opposite situation holds: an *inappropriate* use of a specific CBLE for a particular contextual configuration of knowledge structure complexity/ill-structuredness and stage of learning. We will examine this issue through a further consideration of computer-based drill and instructional hypertext systems.

Depicting the web-like interrelationships of the large number of relevant concepts in complex knowledge areas seems ill-suited for instructional delivery using computer-based drill designs, and indeed it would be difficult if not impossible for the student to be drilled on all the relevant concepts and possible conceptual and knowledge application interactions in such domains (which often involves applying acquired knowledge in new situations that could not be foreseen in the original instructional treatment). Furthermore, the ability to accurately retrieve memorized information is only of limited utility in an ill-structured domain where previously learned material may not exactly apply to a new situation (or may only apply given certain constraints and conditions, hence the need to stress the *assembly* of relevant knowledge). Indeed, one of the primary advantages of the computer-based drill approach for introductory stage learning--providing immediate feedback concerning the correctness of the student's response--is difficult or impossible to implement at an advanced stage of learning in a highly complex and ill-structured area because there is often *no* single correct answer upon which even domain experts can agree (Voss, 1987; Voss et al., 1983). This would certainly be the case for the *Citizen Kane* thematic interpretation domain discussed earlier (although a computer-based drill to promote factual memory for the details of the film might be appropriate if the instructional context involves students at a more *introductory* stage of learning).

In a sense, computer-based drill programs are not appropriate for advanced stage learning in complex and ill-structured content areas precisely because of the close match (discussed above) between typical computer-based drill design features and the learning requirements of introductory stage learning in simple and well-structured domains. As Spiro and his associates have shown (Feltovich et al., 1989; Spiro et al., 1987, Spiro et al., 1988) the learning conditions for introductory stage learning versus advanced stage learning are quite contrasting along a number of dimensions. Computer-based drill programs, as discussed earlier, are effective for introductory learning situations primarily because of several design characteristics that *simplify* the knowledge for the learner. Computer-based drill programs, we therefore argue, are inherently limited in their ability to provide an appropriate instructional environment for complex and ill-structured content, and may in fact be harmful if inappropriately applied in such domains (Feltovich et al., 1989; Spiro et al., 1987).

We stress that the instructional features of computer-based drill programs are not "bad" per se, but rather are appropriate for a certain class of contextual learning situations: those of introductory stage learning in simple and well-structured areas. It is interesting to note that historical trends associated with computer-based drill software are largely consistent with the Contextual Analysis Framework in three main ways: (a) extensive use of these programs at introductory learning levels and in relatively simple and well-structured areas (e.g., mastering arithmetic tables or basic language arts skills); (b) effectiveness of these programs in introductory/well-structured content areas (e.g., Becker, 1988; Roblyer et al., 1988); and (c) avoidance of these designs in more complex and ill-structured areas.

On the other hand, it seems obvious that a complex nonlinear and multidimensional instructional hypertext program of the sort discussed above would be inappropriate for beginning learners in many situations, including helping children to memorize multiplication tables. More complex learning environments have their costs, both for developers and learners. Regarding the latter, the complexity of structure frequently embodied in the design of instructional hypertext programs could be inappropriate for a novice in a simpler domain such as learning the multiplication table. There is a danger of cognitive disorientation when using hypertexts (e.g., being lost in a cascading web of hypertext links and nodes (Beeman et al., 1987; Charney, 1987; Conklin, 1987; Jonassen, 1986; Smith, Weiss, & Ferguson, 1987). In general, the flexibility and nonlinearity of instructional hypertext systems that is so

attractive for advanced stage learning situations may impose extensive cognitive and metacognitive demands on the learner that are unrealistic to expect at an introductory level, demands that could frustrate novice students and inhibit learning. While it is important that a CBLE be as challenging as the learning situation requires, these *systems should not be more complex and difficult than necessary.*

In summary, we have suggested that the same CBLE can be effective in one instructional context and ineffective in a different context, while a second CBLE could have the exact *opposite* pattern of fit to instructional context. It is important that designers and educators analyze the instructional situation and that CBLEs be selected that are appropriate for critical knowledge domain conceptual characteristics and the stage of learning attained by the student.

Utilizing the Analytical Framework

The proposed Contextual Analysis Framework may be used to enrich the understanding of current practices and research findings (i.e., an *interpretive* function) and to guide future use, development, and research in the field (i.e., a *prescriptive* function). In the next two sections, we provide some examples of these types of interpretive and prescriptive applications of the Contextual Analysis Framework.

Interpretive applications. The Contextual Analysis Framework may be used to provide a perspective from which to analyze findings from the instructional computing research literature. For example, a problematic example from the literature concerns *an inverse relationship between grade level and the effectiveness of CAI* (reported by several researchers [Bangert-Drowns et al., 1985; Becker, 1988; Kulik, 1981; Niemiec & Walberg, 1987], but not found by Roblyer et al., 1988). This inconsistency in the effectiveness of CAI across different grade levels has not been rigorously explained in the literature. Roblyer and associates suggest that the effectiveness/grade level inconsistency may be only a characteristic of the older literature on the effectiveness of mainframe-based CAI programs. However, Becker's recent and largely microcomputer-oriented meta-analysis of the effectiveness of long term CAI studies (grades K-12, eight weeks or longer) also found an inverse effectiveness/grade level relationship (Becker, 1988).

This controversy may be explained, however, from the perspective of the Contextual Analysis Framework. As a general curricular observation, lower grade levels provide introductory instruction and cover more well-structured aspects of a domain. In contrast, higher grade levels typically reflect instruction at more advanced levels and deal with more complex and ill-structured facets of a content area (although note that simplifying instructional techniques may be found to some degree at all educational levels (Spiro et al., 1987). As discussed above, CAI approaches (in particular, tutorials and computer-based drill) have cognitive design characteristics that are well-matched to introductory learning and simple/well-structured content areas. It is thus consistent with the Contextual Analysis Framework that CAI would be more effective at lower grade levels, which generally have an introductory and well-structured focus, than at higher grades that require the achievement of advanced stage learning goals in more complex knowledge areas. We suggest that future meta-analytic studies examining the effectiveness of CBLEs could benefit from the explicit consideration of conceptual characteristics of the knowledge domain and stage of learning level described by the Contextual Analysis Framework.

This example illustrates an interpretive application of the theoretical apparatus associated with the Contextual Analysis Framework. But while interpretive applications are important, the framework should also be of value for many designers and educators in terms of helping to guide the development and use CBLEs, a topic we address in the next section.

Prescriptive applications. The Contextual Analysis Framework should be of particular use in predicting the viability of different CBLEs for various learning situations. We will briefly consider two scenarios describing the use of the Contextual Analysis Framework in this manner.

First, suppose a courseware developer is interested in developing CBLEs for college-level courses in several content areas such as electronics, "C" programming, and literary interpretation. Using the Contextual Analysis Framework, the developer would examine the complexity and structure of the instructional domains and the stage of learning of the students. Both the electronics and programming courses are in complex but reasonably well-structured areas and the developer expects some overlap of introductory and advanced stage learning as well. The selection of an ITS for domains with these characteristics and for both introductory and advanced stage learning would be considered appropriate from the perspective of the Contextual Analysis Framework. The area of literary interpretation, however, is a complex and highly ill-structured domain requiring an extensive background in literature, and therefore needs students at an advanced stage of learning in this field. As discussed above, a hypertext learning environment may be successfully used in a complex and ill-structured domain such as literary interpretation, while an ITS would probably not be appropriate (because of the strengths of artificial intelligence in dealing with "routinized" knowledge).

A second scenario illustrating the prescriptive use of the Contextual Analysis Framework involves educators in contrasting subject areas and educational levels who are evaluating different types of CBLEs. A college history teacher, for example, would typically be involved with teaching complex and ill-structured knowledge and therefore would little benefit from an expensive library of tutorial and computer-based drill software that is mainly applicable in simpler and more well-structured areas. The use of sophisticated historical and social science simulations and hypertext learning environments--ideally consisting of a large multimedia "knowledge-base" of text sources, interactive videodisc or digitized video materials, high resolution graphics, and sound--would be more appropriate for such a content area, as would the use of tool software such as word processing for paper writing.

A science educator at the middle or high school levels, on the other hand, could reasonably employ tutorial or computer-based drill programs for certain introductory facets of a well-structured science topic (e.g., acquiring basic terminology and fundamental concepts). At more advanced learning and complexity levels, the teacher could use science simulations (which Roblyer et al., 1988, found to be particularly effective) and tool software/empowering environments for statistical analysis, writing, and even telecommunications (e.g., for sharing knowledge with student colleagues on national and international educational networks [Levin, Riel, Miyake, & Cohen, 1987]).

Flexible use of the Contextual Analysis Framework for assembling ensembles of computer-based learning environments. The framework may be applied to a wide range of instructional situations and types of instructional computing systems. However, we would stress that the framework is *not* intended to be a rigid taxonomy. Rather, the Contextual Analysis Framework should be used in a *flexible* manner to help determine the most appropriate learning situations in which to use a given type of CBLE. Indeed, the framework may be regarded as a theory-based *assembly guide* for CBLEs in which different types of systems are selected according to important contextual learning factors and then used in combination. In other words, the framework could be used in selecting and sequencing *multiple and complementary systems* as part of an instructional *ensemble*. Different CBLEs in a particular ensemble would be used for different instructional purposes. In any knowledge domain, there is very often a *mix* of both simple, orderly, well-structured elements and complex, irregular, ill-structured aspects. Similarly, the learner will be at an introductory level with respect to some aspects of the instructional situation and at more advanced levels for others. Consider, for example, a course in cardiovascular medicine. Some of the technical vocabulary may have quite regular usage patterns and thus may merely need to be memorized. A *computer-based drill* might be used for this aspect of instruction. Other aspects of the course will be very complex but regular. For example, conceptual understanding of muscle fiber physiology involves a variety of interacting concepts and is therefore quite complex; however, the same complex processes happen in the same way for each of millions of muscle fibers. The Contextual Analysis Framework would suggest that *intelligent tutoring systems* have a special appropriateness for advanced learning of complex but regular conceptual material of this type (see Sleeman & Brown, 1982;

Wenger, 1987). On the other hand, a hypertext learning environment like the kind discussed earlier would be most appropriate for developing flexible conceptual knowledge structures required for the highly ill-structured task of extending basic biomedical concepts to clinical cases of cardiovascular pathology.[8]

Conclusion

This report has proposed an analytical framework for understanding important contextual elements associated with learning that may contribute to the success or failure of different classes of computer-based learning environments. While not intended to function as an explicit model for the pedagogical design of specific types of computer-based learning environments, the Contextual Analysis Framework does identify two critical elements related to learning--the characteristics of the knowledge domain associated with conceptual structure and the stage of learning--that any comprehensive theory for the instructional computing field must successfully address. Once a particular computer-based learning environment has been chosen, the *specific* design parameters must be carefully based on the best theoretical and instructional design models that are available. However, it is important that researchers, designers, and educators confront "first questions first" in their attempt to explore and utilize computer-based learning environments in educationally robust ways. The failure to consider important contextual elements of learning related to domain complexity, regularity of structure, and the stage of the learner could result in otherwise well-designed instructional computing technologies being used in inappropriate ways. We view the present articulation of the Contextual Analysis Framework as an initial step toward addressing these "first questions."

[8]In fact, a hypertext prototype based on the same theoretical principles as the *Citizen Kane* program has been developed for exactly this purpose: the *Cardioworld Explorer* (Spiro et al., 1988).

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